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THE EFFECT OF LEVEES ON THE HEIGHT OF THE RIVER BED

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The great flood of 1912 on the Mississippi, which inundated nearly 9,000 square miles of the protected basin, raised again the persistent question as to the effects of levees on the elevation of the river bed. The problem is to a great degree so intangible and so many different situations enter into it that a belief in the general elevation of the river bed due to levees is not strange especially in view of the constant necessity of increasing the heights of levees. The Mississippi River Commission were so embarrassed by the widespread use of the arguments against levees based on this false premise during the recent flood that they reopened the discussion in a report[1] and, from the work of the previous Commissions, reiterated the conclusions that there has been no measurable progressive elevation of the bed of the river during the period covered by the investigations.

The persistent belief is based generally on a number of common though incomplete observations:

1. The building up of a flood plain by successive overflows reducing the slope downwards from the natural levees to the back country gives excellent *prima facie* evidence of an upbuilding bed.

This has been used, especially in the case of the Mississippi River, as an argument against levees. It must be made clear at the outset that there is no denial of the fact that a river may build up its bed, and that a river with such a tendency may continue to upbuild its bed after levees have been constructed along its banks. Where leveed rivers aggrade their channels, the levees are not the cause of the action; rather the upbuilding has gone on in spite of the levees. In case of streams where the tendency to aggradation is lacking, levees not only do not permit continued deposition on the river bed but, on the contrary, seem to have a marked effect in improving a river's channel.

A number of investigations by the Mississippi River Commission sustain this point. The Mississippi River was surveyed during the years 1881-1883 and an average of four cross-sections per mile were taken along the river. The resurvey of the river between the years 1894-1896, especially in the section most improved by levees, yielded cross-sections of greater uniformity and capacity than those of the former surveys, and the conclusion was inevitable that the river channel had been improved by the confinement of the waters. A marked characteristic in the change was the consistent lowering of the crests of all bars in the crossings of the river. In 1880, the Mississippi near the mouth of the Atchafalaya River possessed cross-sections of unusual variety. The depth of the river showed no relationship to the spreading of the waters and, in many places where the river was wide, a deeper section was obtained than in the contracted portions. In 1904, after levees had been constructed, the river showed unmistakable signs of cutting more regular cross-sections and the general flow of the low water stage was improved. These cross-sections were taken during low water, inasmuch as it was the belief that any silting up of the channel would be registered more convincingly by the gage readings of the low water stages than of the flood stages. Similar records come to us from the Po. During the first quarter of the nineteenth century the mean of the low water readings was 10.4 feet, during the second quarter 10.3 feet, and during the third quarter 10.1 feet. There was then, during seventy-five years, a slight though persistent lowering of the low water level although, as will be shown later, the flood heights had risen steadily. Such records are not compatible with a filling channel. In like manner, a consistent falling of the low water stages of the Rhine has been recorded at Cologne and Emmerich.

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[1] Report of the Mississippi River Commission for the year ending June 30, 1912. pp. 3715-3717.

The striking feature of the flood of 1897 on the Mississippi River[2] was the greater height of the flood wave in the lower portions of the river than the stage at the upper river stations led the engineers and the riparian proprietors to expect. The proposition was established, furthermore, that this feature was not abnormal, but, on the contrary, such a change in the regimen of the river had taken place that any flood wave passing Red River Landing (765 miles below Cairo) at a high stage may be expected to cause a flood wave at Carrollton (950 miles below Cairo) a foot or more higher than a flood of the same height would have caused fifteen or twenty years ago. The explanation of this change in flood height has been that it resulted from the upbuilding of the river's bed, and, in this particular case, that the bed was filling about and below Carrollton. If such were the case, it is obvious that the effect, in the instance of low flood waves, would be proportionally more noticeable than in the case of the high. Tables of low flood waves show no tendency whatever towards an increase in the height of the low flood wave at Carrollton and the theory of a filling channel must be abandoned in this instance.

The experiment was conducted somewhat as follows: The low floods, which have been recorded since 1872 at Red River Landing and Carrollton, were tabulated. The gage readings, at Red River Landing, fall into three groups, 22.3 feet, 21.4 feet and 19.3 feet approximately. The ratio of the Carrollton stage to the Red River Landing stages, about 19.3 feet, are found to be uniformly less than those of the other two stages and, furthermore, the ratios have increased somewhat during later years. Another reason than the upbuilding of the river bed must be found to account for this situation. It can be shown that the carrying capacity of the river between Red River Landing and Carrollton has been increased. The effect of this would be shown especially during excessive stages of the river, and the greater distribution of the waters directly below the former station would tend to diminish the high water slope while little or no change would be recorded at the latter station because of this change. It was not so much that the flood height had been increased at Carrollton as that it had been lowered at Red River Landing.

2. On portions of the river's course, such as alluvial fans and deltas where the velocity of the river changes suddenly, the situation, while not different from the preceding, offers a greater opportunity for a superficial judgment against the levees. Here again it is not denied that the bed of the river

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[2] Report of the Mississippi River Commission for the year ending June 30, 1900. p. 4551.

aggrades, although, in the same breath, the assertion is made that levees not only cause no deposition of sediment but diminish the rate of deposition.

Instances have been cited from many rivers. Some rivers of Japan are reported[3] to have raised their beds. These occur, however, on the alluvial fans where the torrential rains bring great quantities of detritus from the mountain slopes to be deposited on the plains. The quantity of sediment may be so great and the plains so narrow that the entire lowland reach of the river is included in the fan limits. In some instances, where protecting embankments have been built, the river is forty feet above the plain, and the railroads across the lowlands have been placed in tunnels on a level with the surrounding country, underneath the streams, to avoid the inconvenience of floods and the constant demands of shifting the road-bed to the caprices of the upbuilding fan.

It would not be strange if the same condition obtained in the Hoang Ho, for the river brings a great volume of silt from the mountains and plateaus and an upbuilding process on the great river plain is easy to forecast. Many accounts of this river assert that where it is leveed the bed has risen above the surrounding country, but all these statements seem to eminate from a casual observer whose information was not altogether founded on careful investigation. The Mississippi River Commission published[4] in 1890 a letter from China, written by a person of competent authority, in which enough data are included to lead one to believe that no such silting as to raise any part of the bed above the adjacent country has ever taken place.

With the preservation of many ancient gages on the Nile, records covering a thousand years or more show a persistent upbuilding of the Nile Valley from Assuan down to the Mediterranean. The Roda Island gage, near Cairo, records a stage of river necessary for irrigation four feet above what was needed in A. D. 861, which indicates a general rise at the rate of 0.39 foot per century, while similar records below the last cataract give a rise of 0.43 foot per century.[5] This is apt to be the case in all delta building streams. The deposit of sediment at the mouth and the extension of the river's length diminish the slope of the bed; this in turn decreases the velocity of flow and causes deposition of some of the load of the stream until the slope is again restored. The prevention of the spread of the waters and the loss of velocity by the building of jetties has demonstrated the effectiveness of levees to resist this tendency if not to overcome it. Even in the Nile, the change has been so slow as to be practically imperceptible.

It is probable that the great extension of alluvial fan and delta in the case of the Po River has given rise to many conflicting reports from the Italian stream. The tributary streams which flow from the Alps upon the plains north of the Po demand for the transportation of the sediment a steeper slope than the lowland has and deposition takes place. This upbuilding will go on until a more or less permanent slope is attained. The Adige, so often used as an example of a stream whose levees are higher than the surrounding country, is a type of this kind. The bed of this stream would rise if left in its natural state and it can hardly be expected not to do so after the levees have been constructed.

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[3] Harcourt, L. F. Vernon : Rivers and Canals. Vol. I, p. 167.

[4] Report of the Mississippi River Commission for the year ending June 30, 1890. pp. 3093-3098.

[5] Thomas, B. F., and Watt, D. A.: Improvement of Rivers. p. 7.

The confinement of the sediment between the banks of the streams, which is discussed later, causes a more rapid outbuilding of the delta. This increase which is noticeable in the case of the Po will, because of increasing the length of a stream, diminish the slope and cause a deposit between the embankments. Thus, measurements of low water stages near the mouth of the Po will in all likelihood show a slight increase in the average reading in succeeding years. The increase in length of the Mississippi River is about four miles per century. The Mississippi River Commission figures that, with the existing slope, this increase of length would raise the high-water level at New Orleans about seven-tenths of a foot per century or at the average rate of eight-hundredths of an inch per year.

3. The necessity of raising the height of the levees to withstand the floods is used as an argument in favor of the upbuilding bed hypothesis. As the confinement of the waters becomes more and more succssful, higher and higher levees are demanded. On the Po, where there has been a decrease of the mean low water during seventy-five years following the introduction of levees, the flood heights have risen steadily.

As the percentage of completed levees increases and the waters, instead of spreading over the broad flood plain are more and more constricted between artificial walls, the high water level will be raised. On the Mississippi River, at the present time, the levees are 81.6 per cent. completed and the uncompleted portions release large volumes of water which detract from the height of the flood crest. Thus, the high water of 1912, which exceeded all previous floods in height at all stations except Vicksburg, had its flood crest lowered by the escape of water through crevasses and over the uncompleted levees. At Greenville, Miss., on April 12, this flood had a stage of 50.75 feet with a previous highest at 49.1 feet during 1903. The Commission estimates that had the water been confined, the 1912 flood at this station would have been 52.8 feet.[6] The provisional grade determined for Greenville after the 1903 flood, to which the Commission has not been able to raise the levees, was 53.1 feet or 2.35 feet above the 1912 flood. The provisional grade is based on the estimated confined height of a flood wave and this estimate places the flood within .3 of a foot of the provisional grade. A new provisional grade based on the 1912 flood, which will be higher than the former one, will set a new height for levees at Greenville. It is absurd to argue that this increasing height of levees arises from deposition along the bed.

The confinement of the waters between levees and the consequent high stages of the river during floods give a greater slope and therefore a greater velocity to the current. The expectation would follow that, instead of depositing sediment, the transporting power of the stream would be increased and scour of the bed would result. It must be remembered that while the water has been constrained, the sediment which formerly was spread over the flood plain is now confined between the levees and the water must carry a larger load, but an increase in the carrying capacity has been effected which permits the waters not only to carry this additional volume of sediment but also to pick up more. A noticeable effect of this appears in the increase in delta building rate. Lombardini has calculated that the annual increase in area of the Po delta, for the period from 1300 to 1600, was 127 acres, but between 1600 and 1830 the rate was 324 acres. The introduction of levees on deltaic portions of a flood plain, because of the concentration of the flow, results in considerable scour; however, when normality is reached, under the new conditions, the increasing length of the river, which is caused by delta building and which goes on at a more rapid rate because of the confinement of the silt between levees, will result in slight, almost negligible upbuilding of the bed, some part of it being directly traceable to levee construction.

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[6] Report of the Mississippi River Commission for the year ending June 30, 1912. p. 3721.

There are other phases of river activity under the present uncompleted state of levee construction which cause temporary deposits on the river bed to the embarrassment of the low water navigation. Crevasses occur during seasons of exceptional high water. The primary evils of such weaknesses in the levees are not pertinent to the discussion but, of secondary importance, are the deposit of sediment over valuable land and the lessening of the stream flow thereby to such an extent that a deposit may also take place in the river bed. The menace of water by levee construction demands a sure knowledge that the levees will withstand the force of the river; but if it does not, while people may escape destruction by heeding the warnings, they cannot escape the loss which results from the heavy deposit of silt dropped by the stream when it spreads beyond the limit of its confines. At the same time, in the bed of the stream there occasionally results a silting due to the loss of carrying power. This condition is analogous to two troublesome factors existing in the Mississippi River, *viz.*, the widening of the stream and the separation of a stream by an island, conditions which do not, however, fall into different categories so far as their results are concerned. In a number of instances on the Mississippi, the river increases in width as it leaves a pool section from half a mile to two miles within a short distance. In other cases the stream is divided by islands. These are the places where dredging has been most necessary and where the experimental wing dikes were constructed in the hope of ameliorating the river channels.

A deposit also takes place on the river bed under a rapid fall in the stage of a river. This deposit is not permanent, but it is moved during the next rising stage of the river; in the meanwhile, however, it is a detriment to low water navigation. If the fall in stage is gradual, the river generally distributes its load and carves out a low water channel. The fall in stage due to crevasses will be prevented to a great degree by an efficient levee system, but the sudden fall in stage due to the distribution of rainfall can be overcome only by withholding enough water in storage to regulate the rate of fall in the stage of a river.

4. In a river free to develop meanders, the tendency to increase the radius of curvature increases the length of the stream and consequently diminishes the slope frequently to such an extent that the lessened velocity is not sufficient to transport the sediment. In such a case there would be an upbuilding of the upper part of the river bed to give a velocity capable of doing the work. This tendency rights itself in two ways. First, the power of the river to erode decreases as the carrying capacity of the water becomes increasingly taxed; or again the river shortens its course by a cut-off and additional power is given to the flow. Under the action of a meandering stream the upbuilding of the river bed may go on for a season. If the river is kept in a stable channel and the tendency to increasing the radius of meanders on one hand and to cause cut-offs on the other is halted, the actual effect of levees, far

from being a detriment to the channel, is beneficial. Furthermore, it may be expected that, when river regulation has become well established, much of the sediment now given to a stream from insecure banks or unclothed slopes will be eliminated and the power of the stream to deepen its channel will be greatly enhanced.

SUMMARY

The observation of the low water gages of rivers proves quite conclusively that there is no persistent upbuilding of the bed due to levees.

On streams or portions of streams where, from the nature of the conditions, aggrading is in operation, the upbuilding of the river bed after levees have been constructed will probably continue.

Deltas increase in area more rapidly in a leveed river and the increase in the length of the stream diminishes the slope and results in a slight deposit on the river bed. The amount is so small as to be imperceptible during a score of years.

The increase in the height of levees can be accounted for by the success of the engineers in confining an increasing percentage of the flood waters.

The elimination of some of the sediment from a stream flowing through its flood plain will minimize the amount of the temporary deposits in beds of rivers and furnish additional power by which the channel may be cleared of bars.